Electric field devices for the EDM prototype ring

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Abstract

In the framework of the Physics Beyond Colliders (PBC) study at CERN, the Electric Dipole Moment (EDM) working group is investigating the feasibility of building a storage ring to precisely measure the permanent electric dipole moment of the proton [1]. Protons are stored in an EDM ring at the so-called ‘magic’ energy of 253 MeV using only electric field elements in order to ensure that spin and momentum vectors precess horizontally at the same rate. For a proton with longitudinal spin, any EDM manifests itself as a measurable vertical spin precession.

As a preparation for this main ring, a prototype ring (PTR) is proposed to demonstrate the feasibility of technologies that are not yet operationally confirmed. The PTR is to be small and simple to contain the cost, and will therefore have a circumference of c~100 m. The power supply voltages of the PTR will be limited to 200 kV.

The main electric field ring will store protons at an energy of 30 MeV for the initial stage and 45 MeV for the final stage (where frozen spin optics will be pursued). This article describes the challenges related to the electric field quadrupoles of the PTR as well as to the injection section. The feasibility of the equipage will be discussed and the outstanding issues are highlighted.

Introduction

The PTR is planned in two stages: a 30 MeV proton ring using electric field dipole, while the second stage foresees an upgrade to 45 MeV protons using a combined electric and magnetic field dipole. The aim of this paper is to determine the boundary conditions for the design of the quadrupoles of these rings as well as the assessment of the limitations for the injection elements.

Injection

Injection into the two proton beam is foreseen in 2 adjacent straight sections. Since the straight sections are terminated with QF quadrupoles, the overall radial size of this element determines to a great extend the injection angles. The QF design therefore should minimise the horizontal width of the device. To inject, the beam is deflected by an electrostatic septum followed by a fast pulsed separator (fast deflector).

Since the revolution time of the ring is around 1.5 μs and at least 2 bunches need to be injected (clockwise (CW) and counter clockwise (CCW)), a rise and fall time of the kicker is needed of < 250 ns, ideally even 200 ns to allow the injection of 4 bunches in total (2CW + 2CCW).

The septum and its (anode) support need to be curved to limit the gap to 70 mm wide, while displacing the beam by 16 mm. The septum can be made of bent or segmental 1 mm thick stainless steel. Alternatively, wires can be used to obtain a thinner septum. Ideally a 2 mm material would be used to keep radiation activation as low as possible. By keeping the gap limited to 70 μs and the revolution time required below 210 μs, the cathode can be made of stainless steel.

The septum will be supplied with DC voltage and needs to be conditioned to above 255 kV prior to operation. The septum and electrode gap width will be fixed, potentially making conditioning more delicate, but this reduces the complexity of the device, hence its cost significantly.

The stripline kicker gap width is taking into account the beam sagitta using straight electrodes. Two pulse generators will be connected to the kicker, each powering an electrode. Due to the fast rise time and current, the most suitable power generator topology will be that of the inductive adder type [2]. The characteristic impedance of the stripline kicker (50 Ω) was chosen as a starting point to be compatible with the inductive adder generator. However, the detailed design of the actual kicker is still to be finalised which may lead to small changes in the electrode shape and tank inner diameter.

The table shows the principal requirements assumed for the quad in the 45 MeV PTR. A quad design is proposed based on the lattice requirements, respecting the material physical space is stable and keeping the horizontal width of the device to a minimum. Ideal hyperbolic shaped electrodes are housed in a 1.0 m diameter vacuum vessel. The field precision of the electrode shape was first determined in 2D using Altair Hyperworks Flow3D, and subsequently using Cobham Opera software for the 3D, in a similar approach as was done for the EDM ring elements [3]. The requested stability of the power converters is ±1%.

Conclusion

To inject the polarised proton beam, the long straight sections and large beam aperture required impose relatively high voltages on the injection elements. The QF quadrupoles are designed to minimise their transverse footprint, as to minimise the required kick of the injection elements.

Conditioning of sparking under nitrogen at atmospheric pressure is efficient, and remove any DC (dark) current that was observed under vacuum.

Conditioning under argon @ 10 mbar seems to polish the wires. However no improved voltage hold-off capacity observed yet. Max. field between electrodes achieved so far: 3 MV/m (gap 10 mm).

References

[1] M. Lamont et al., “Feasibility study for constructing a high energy electron beam ring to search for Electric Dipole Moments of charge particles”, CERN yellow report to be published 2019


Fig. 1: Stripline kicker gap width is taking into account the beam sagitta using straight electrodes. Two pulse generators will be connected to the kicker, each powering an electrode. Due to the fast rise time and current, the most suitable power generator topology will be that of the inductive adder type [2]. The characteristic impedance of the stripline kicker (50 Ω) was chosen as a starting point to be compatible with the inductive adder generator. However, the detailed design of the actual kicker is still to be finalised which may lead to small changes in the electrode shape and tank inner diameter.

Fig. 2: The septum and its (anode) support need to be curved to limit the gap to 70 mm wide, while displacing the beam by 16 mm. The septum can be made of bent or segmental 1 mm thick stainless steel. Alternatively, wires can be used to obtain a thinner septum. Ideally a 2 mm material would be used to keep radiation activation as low as possible. By keeping the gap limited to 70 μs and the revolution time required below 210 μs, the cathode can be made of stainless steel.

Fig. 3: The septum and electrode gap width will be fixed, potentially making conditioning more delicate, but this reduces the complexity of the device, hence its cost significantly.

Fig. 4: The septum test cell: top Ti cylinder, cathode & anode of CNT wires, septum anode.

Fig. 5: Main septum, current density on a CNT wire anode,Argon gas discharge conditioning.